Appendix 1

THE PROBLEM OF LAMPENFLORA IN SHOW CAVES

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Abstract: Lampenflora is a typical problem of show caves, because the light that is necessary for the visitors supplies enough energy to some plants, mainly algae and mosses, which may grow to the point of defacing and damaging seriously the cave itself.
After a description of the main characteristics of lampenflora and a detailed list of the environmental conditions contributing to its development, the best methodology to control such a development with particular attention to an easy and successful implementation is here described.

Key words: lampenflora, lighting, control of lampenflora.

INTRODUCTION

In a wild cave the flora, i.e. any kind of plants, exists only in a part close to a natural entrance where the outside light reaches the cave environment. According to the species, the plants may grow inside a cave until the light intensity ranges between one to three orders of magnitude less than outside.

Most of the show caves are fitted with a lighting system and in an area more or less around a lamp plants can develop. In general these plants are algae or mosses but sometimes also ferns till superior plants may develop and grow. This phenomenon was firstly studied mainly by Austrian scientists (Kyrle, 1923; Morton & Gams, 1925) and, later, in France (De Virville, 1928). A rather exhaustive book on the cave flora, with many references dating back to the XVIII century, is that due to Morton & Gams (1925).

Only in 1963 the word "lampenflora" (a German word which means "plants of the lamp") was firstly introduced by Dobàt (1963) and is presently adopted everywhere in the world to identify any kind of plants growing in the vicinity of lamps.

WHAT IS LAMPENFLORA AND HOW IT DEVELOPS

The plants classified as lampenflora range, in general, from cyanobacteria (also known as blue-green algae), algae, lichens, mosses to ferns. Cyanobacteria, green algae and mosses are the most common components of the lampenflora in show caves, their abundance varies from cave to cave (Padisàk *et al.*, 1984; Grobbelaar, 2000; Aley, 2004). Algae and cyanobacteria exist in wild caves (Claus 1962, 1964; Hajdu, 1966; Kol, 1967) also in the dark sections. This means that a release of spores brought in by the visitors is not strictly necessary for a successive growth of these algae. When a cave is developed as a show cave the algae proliferate in the vicinity of the light sources thanks to the energy released by the lamps.

In general the lampenflora is firstly composed by algae at the beginning of its development, to be followed by mosses, ferns and sometimes by vascular plants (Mulec & Kosi, 2009). The negative effects of lampenflora is due to the fact that plants may produce weak organic acids, which in time can corrode both limestone and formations (Aley, 2004). When a prehistoric cave is concerned the paintings may be seriously damaged as happened in Lascaux cave in France (Ruspoli, 1986). In addition, without any intervention the lampenflora spread rather quickly (e.g. in Baradla cave, Hungary (Hazslinszky, 2002), lampenflora doubled in 7 years) and may become an important source to colonise wide areas. A typical example is observed in Cango Caves, South Africa, where large surfaces of coral-like formations far away from the lighted section of the cave are covered by green algae.

Lampenflora's growth and distribution depend on light intensity, temperature, moisture and substratus.

The lux (symbol: lx) is the unit of illuminance and it is used to measure the intensity of the light, as perceived by the human eye that hits a surface. As a rough indication of the light intensity resulting in the development of 85 % of the lampenflora, a value around 40 lux was measured when the light was switched on for most or all the time that the caves were open. A continuous lighting yields more lampenflora growth than short periods of lighting for the same length of time because the adaptation of plants to light and dark phases requires both time and plant energy (Aley, 2004). The established lampenflora populations can survive long periods of very low levels of illumination or total darkness (Johnson, 1979).

Chlorophyll (types a and b) has two absorption peaks, in the ranges 430 – 490 nm and 640 – 690 nm. Therefore if a lamp has an emission spectrum in the range 500 to 630 nm the contribution to the photosynthesis process of green algae is reduced without important aesthetic problems. In Mammoth Cave, USA, lighting with LED at an intensity of 49.5 lx and a yellow light (595 nm) prevented regrowth for 1.5 years after complete lampenflora removal (Olson, 2002).

Sometimes a UV irradiation was used to suppress the lampenflora on account of its germicidal effect (Mulec & Kosi, 2009). Recently in Grotta Gigante, Trieste, Italy, a new set of germicidal lamps, provided with an electronic starter, which obtained the *2008 Green certificate*, in order to inhibit the development of lampenflora and to ensure an environmentally-friendly use of the cave were installed. These lamps, whose use aims at keeping under control the development of lampenflora, turn on when all the other lights in the cave are turned off (Fabbricatore, 2009).

Incandescent lamps produce an increase of the temperature and a decrease of the humidity. Within some tens of centimetres from the lamp the increase of temperature may be of the order of 10 °C and the decrease of the relative humidity to 70 – 80 %, this condition results in an algal growth unless the decrease of humidity is excessive and the algae cannot proliferate (Mulec & Kosi, 2009). In fact lampenflora develops on moist or damp surfaces and therefore soft surfaces as cave sediments and moonmilch provide higher moisture storage than hard surfaces with the chance of luxuriant growths (Aley, 2004).

HOW TO CONTROL LAMPENFLORA

The most obvious action is the reduction of energy supply by both a reduction of the light emitted and the adoption of a light spectrum with a low emission in the wavelength absorbed for growth the lampenflora (Smith & Olson, 2007). Unfortunately such an action

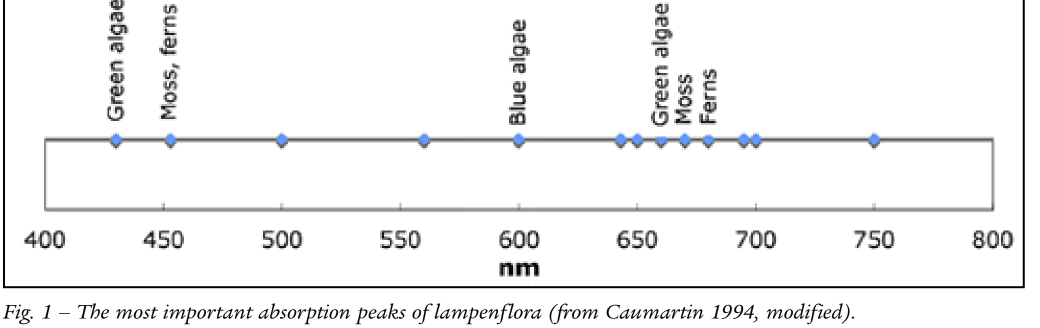

Fig. 1 – The most important absorption peaks of lampenflora (from Caumartin 1994, modified).

is not enough effective to solve the problem. Nevertheless it is convenient to use lamps with an emission spectrum poor of the wavelength mostly absorbed by lampenflora. In Fig. 1 its is reported a graph where the maximum of the absorption peaks are reported. The frequencies with the maxima from 460 to 453 nm around 600 nm and from 653 to 700 (particularly the latter) are the most dangerous for the proliferation (Caumartin, 1994). Preliminary experiments with cold cathode lamps reached a reduction of the growth of a green alga (*Dunaliella salina*) down to 57 % of the control (Antrox, 2009).

The technique of switching out the light for a prolonged time interval (e.g. one month) counteracts the proliferation of photosynthetic organisms in caves but may favour the diffusion of especially resilient organisms as *Phormidium autumnale* (and generically cyanobacteria) by reducing competition (Montechiaro & Giordano, 2006).

It must be stressed that, notwithstanding the reduction of light plays a positive role in reducing the proliferation of lampenflora, sometimes a moss intertwined with cyanobacteria may cover relatively wide areas which were only occasionally illuminated (Giordano *et al*., 2001).

When lampenflora proliferates, it is necessary to destroy it with chemical compounds. The herbicides have the disadvantage of being sometimes highly toxic for cave fauna and also the personnel must pay a special care. For this reason these biocides as DCMU, Atrazine, Simazine, Karmex, etc., are absolutely inappropriate in caves (Mulec & Kosi, 2009).

A comparison among an herbicide, sodium hypochlorite and sodium chlorate at the following concentrations:

Karmex™ Du Pont	3 g/L water
Sodium hypochlorite	2.75 % Cl
Sodium chlorate	30 g/m^2

gave similar results, but sodium hypochlorite had a faster effect while the results obtained with sodium chlorate were less homogeneous. The runoff of the solution should preferably be collected and disposed outside the cave. In any case after the treatment the surface should be rinsed with water.

A test to evaluate the corrosive action of sodium hypochlorite was carried out on some broken formations. After 10 minutes of treatment about 41 mg/m^2 were dissolved without any further increase over 17 hours (Bertolani et al., 1991). For this reason the treatment with sodium hypochlorite is currently adopted in the Frasassi Caves, Italy, since many decades with no disadvantages for the formations, which are as shining as when, they were discovered. But according some authors (Faimon et al., 2003; Mulec & Kosi, 2009) it represents a burden for the cave environment.

Therefore hydrogen peroxide, which is an environmentally friendly agent was proposed (Grobbelaar, 2000). The threshold concentration for the destruction of lampenflora was found to be 15 % vol. but the solution attacked the carbonates with a dissolution rate around $2*10^{-2}$ mol m^{-2} h^{-1}. In order to avoid such an effect a preliminary peroxide saturation was obtained by adding of few limestone fragments into the peroxide solution at least 10 hours prior to its application (Faimon et al., 2003).

CONCLUSION

There are different actions to control the development of lampenflora in show caves. First of all, there is the reduction of energy introduced into the cave by the lighting:

- Lights switched on when necessary only
- Minimum distance of indicatively 1 m between lamp and cave wall or formations
- Emission spectrum with minima in the ranges 430 – 490 nm and 640 – 690 nm
- UV lamps switched on when visitors are absent

These actions can be implemented together or each one according to the local situation and possibilities. Obviously the lamps switched on only when the visitors are present in their vicinity reduce the energy release as well as the cost of electric energy. Since the amount of radiation emitted from a lamp decreases as the inverse of the square of the distance, it is always convenient to avoid the placement of lamps too close to walls or formations also because the temperature increase can interfere with the growth of formations. A spectrum poor of the wave length mostly absorbed by lampenflora can be easily obtained with discharge lamps (cold cathode lamps) or LED. The effect of UV irradiation was found to have only a transitory suppressing effect (Dobat, 1998). In addition the effective range is between 50 and 70 cm for a 30 W lamp and therefore in order to have a wider area treated to a distance, e.g. of 3 m, a 400 W lamp would be required or a multiple low power lamps (Kermode, 1975). Some experiments are being carried on presently, as in Grotta Gigante (Trieste, Italy) where the whole electrical system has been replaced recently (Fabbricatore, 2009). The result of the UV irradiation will be appraised in the very next future. In particular its effects should be considered with reference to the expenses of installation and maintenance.

Once the lampenflora is present, it is necessary to avoid its further development and destroy it by chemical methods:

No herbicides! Too toxic for the cave environment
Sodium hypochlorite 5 %
Hydrogen peroxide 15 % vol

Herbicides, used frequently in agriculture, must be avoided because their degradation in the cave environment is rather slow and their toxicity may affects seriously the cave fauna. Sodium hypochlorite treatment releases gaseous chlorine, which may have bad side effects on the cave fauna. Some air circulation may avoid such bad effects. Hydrogen peroxide, once it is saturated with calcium carbonate, is surely the most "friendly" chemical compound, but its use required some precautions by the personnel, while the personnel can apply the sodium hypochlorite without special attention.

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